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ENGINEERING THE FUTURE OF FULL-SCALE PROPULSION TESTING

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ABSTRACT

Year 2000 has been an active one for rocket propulsion testing at the NASA John C. Stennis Space Center. This paper highlights several major test facilities for large-scale propulsion devices, and summarizes the varied nature of the recent test projects conducted at the Stennis Space Center (SSC) such as the X-33 Aerospike Engine, Ultra Low Cost Engine (ULCE) thrust chamber program, and the Hybrid Sounding Rocket (HYSR) program. Further, an overview of relevant engineering capabilities and technology challenges in conducting full-scale propulsion testing are outlined.

SSC PROPULSION TEST CAPABILITIES AND ACTIVITY

NASA's Space Transportation Plan calls for both evolutionary and revolutionary advances in Space Propulsion as an enabling element for lowering the cost of access to space. Near-term and longer-term Space Transportation roadmaps have been developed (cf. Ref. 1) and are comprised of both chemical and non-chemical propulsion technologies required to enable 1st Generation (e.g., Shuttle), 2nd Generation (e.g., Reusable Launch Vehicle (RLV)), 3rd Generation (e.g., Airbreathers), and 4th Generation (e.g., non-traditional propulsion devices) space transportation. In order to reduce the risk to flight programs, extensive ground testing is anticipated as part of the coming technology and/or vehicle development efforts. Therefore the entire suite of NASA development and test facilities must be prepared to accommodate the testing needs. This paper summarizes how the NASA John C. Stennis Space Center (SSC) is postured to meet the testing demands of the next few years.

The John C. Stennis Space Center (SSC) is NASA's Lead Center for Rocket Propulsion Testing, giving the center oversight responsibility for all of NASA's rocket propulsion test assets. In addition, Stennis Space Center is the location of a variety of unique rocket propulsion test areas (A, B and E complexes) and capabilities.[2-4] Propulsion test services at SSC are available to NASA, Department of Defense (DoD), other government agencies, academia and industry.

The year 2000 has been an active one for large-scale propulsion testing at SSC as shown in Table 1. All test positions at the three major test areas were occupied (A, B, and E complexes). Major test programs included X-33 Aerospike, RS-68 for the Evolved Expendable Launch Vehicle (EELV), SSME for Shuttle, and several small and large component development test projects. The general characteristics of each Test Complex and a profile of select current and future test programs are more fully addressed next.

A Complex

The A Complex consists of the A1 and A2 test stands which are similar in design and are depicted in Fig. 1. Each test stand can be supplied with liquid hydrogen (LH_2) and liquid oxygen (LO_2) from low pressure run tanks, which are in turn filled/supplied from propellant barges via the canal system. The stands are also supplied with support fluids, gaseous helium (GHe), gaseous hydrogen (GH_2) and gaseous nitrogen (GN_2), for use as purge and pressurant gases. Each stand is designed for an approximate thrust load between $0.7 \cdot 10^6 - 1.7 \cdot 10^6$ lb_f depending on the test article configuration. Further information regarding stand capabilities is documented in the Test Facilities Capability Handbook.[2]

The A1 test stand is currently occupied with the testing of Reusable Launch Vehicle (RLV) propulsion technology systems. Specifically, single-engine testing of the LO_2/LH_2-based Boeing Aerospike engine (XRS-2200) for the Lockheed-Martin X-33 demonstrator vehicle has just been

* Engineering Division staff members.

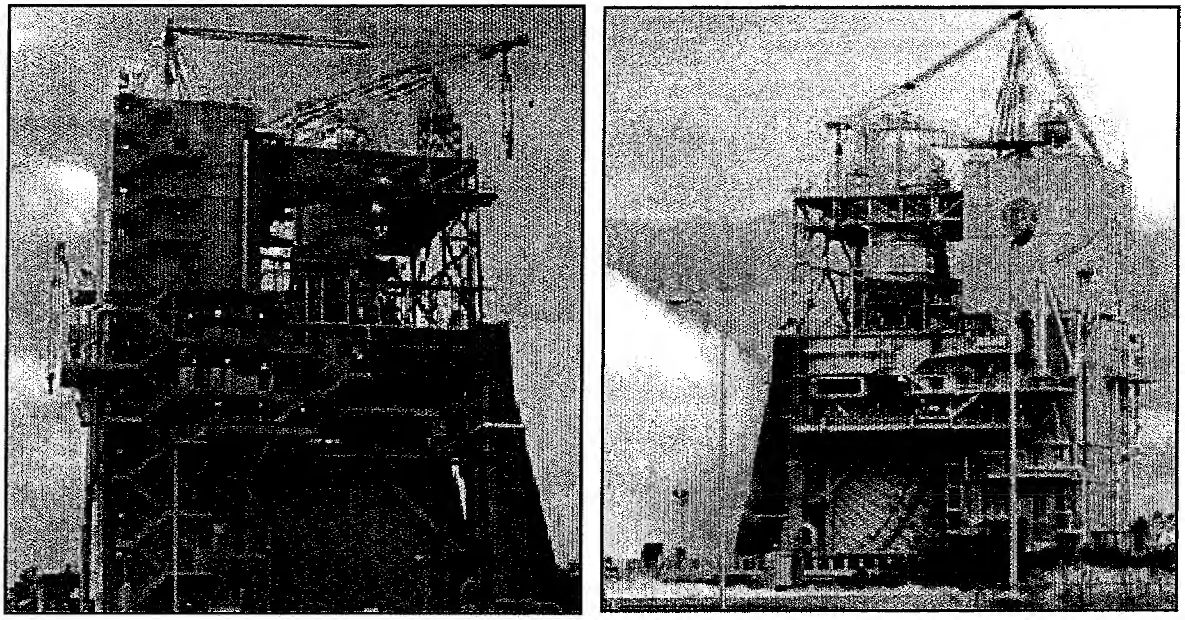

Fig. 1. A Complex; **(a)** Test stand A1 and **(b)** Test stand A2.

concluded. This was preceded in the year 1999 by extensive testing of the Power Pack Assembly (PPA). Final preparations are being made for testing of the *dual-engine* configuration of the XRS-2200 engine. Various flight acceptance and certification testing of the Space Shuttle Main Engine (SSME) continues to occur at test stand A2.

B Complex

The B Complex, as shown in Fig. 2, is a dual-position system with one side of the stand designated as B1 and the other side designated as B2. Each test stand can be supplied with liquid hydrogen (LH_2) and liquid oxygen (LO_2) propellants from run tanks and a barge and canal system. The stands are also supplied with support fluids such as, for example, gaseous helium (GHe), gaseous hydrogen (GH_2) and gaseous nitrogen (GN_2) for use as purge and pressurant gases. Each stand is designed for an approximate thrust load between $6 \cdot 10^6$ – $11 \cdot 10^6$ lb_f depending on the test article configuration. Further information regarding stand capabilities can be found in Ref. 2.

B Complex activity is concentrated on the testing of propulsions systems for the Evolved Expendable Launch Vehicle (EELV) program, specifically the Boeing Delta IV vehicle. Testing of the Boeing LO_2/LH_2-based RS-68 engine is underway and continues beyond 2003 at test stand B1. Testing of the Common Booster Core (CBC) configuration (the RS-68 engine and its propellant tanks) shall begin in the current year on the B2 side and is scheduled to continue through most of year 2001. The A and B test complexes thus provide four test positions for large scale engines (prototype or flight type), and are typically utilized for final development, or qualification, and acceptance testing. The precursor development tests for these engines (pumps, powerheads, thrust chambers, etc.) may be performed at subscale or full-scale at the E Complex which is described below.

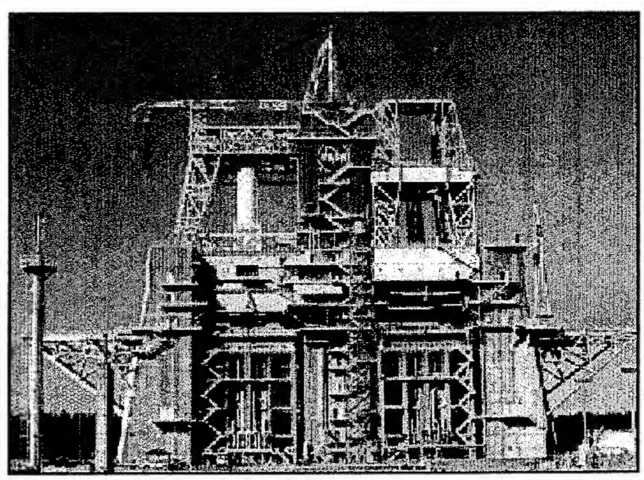

Fig. 2. B Complex with B1 test position on the left hand side, and B2 position on the right hand side.

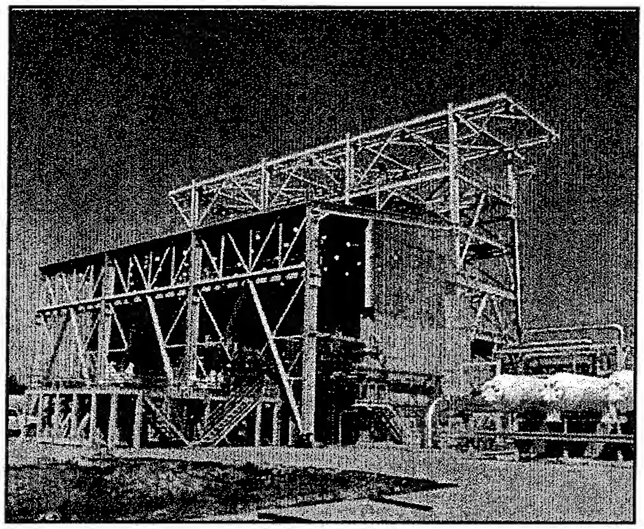

Fig. 3. E1 Test Stand comprised of Cells 1, 2 and 3.

E Complex

The E Complex currently consists of three distinct test stands, E1, E2 and E3 with detailed stand capabilities delineated in Ref. 2. Notably, there are a total of *seven* test positions (or cells) offered within these three stands. First, the E1 test stand is comprised of three individual test cells and is shown in Fig. 3. This versatile test stand can hence conduct multiple test projects and allows for testing of various combustion devices, turbopump assemblies and other rocket engine components. More specifically, E1 Cell 1 can accommodate liquid propellant-based and hybrid-based test articles up to $750 \cdot 10^3$ lb_f thrust (horizontal position). E1 Cells 2 and 3 are designed for various LO_2 and LH_2 turbopump assembly testing. The component testing is enabled here by the ability to supply extremely high-pressure propellants (up to 8500 psia) and gases (up to 13,500 psia) as required. Facility upgrade plans include installation of high and low pressure RP1 systems to allow for the development of hydrocarbon-fueled engines.

The multi-cell E2 test stand was originally intended to provide high enthalpy flows to support materials development testing, a.k.a. "panel testing", for the National Aerospace Plane (NASP) program. The facility, which is designed to handle thrust loads up to $100 \cdot 10^3$ lb_f, has recently been fully activated and used to perform pre-burner testing with LO_2 and RP1, and is currently being upgraded to accommodate a variety of component and engine development testing. Facility upgrades in progress will implement low and high pressure liquid hydrogen systems for component developments.

The E3 test stand consists of two individual test cells that are primarily designed for component and pilot-scale combustion device testing. E3 Cell 1 accommodates test articles up to $60 \cdot 10^3$ lb_f thrust (horizontal position) that employ the following propellant combinations: LO_2 or GO_2/hydrocarbon, GO_2/GH_2, and hybrid. LO_2/hydrocarbon and hybrid-based test articles can be tested at E3 Cell 2 up to thrust levels of $25 \cdot 10^3$ lb_f (vertical position). Notably, a unique and important feature of E3 Cell 2 is the capability to demonstrate hydrogen peroxide (H_2O_2) based test articles. Facility upgrades in progress shall allow for longer duration H_2O_2 testing in both Cells 1 and 2.

A variety of test programs were conducted at the E Complex during the past year. Test stand E1 Cell 1 has been used to test TRW's Ultra Low Cost Engine thrust chamber (ULCE). Low cost is achieved through the use of a low-pressure combustion chamber, an ablative-lined chamber/nozzle, simplified propellant feed systems and a single Pintle injector element.[5] TRW, Inc. successfully completed demonstration of their Ultra Low Cost Engine (ULCE) Pintle-based design with a nominal thrust of $650 \cdot 10^3$ lb_f using LO_2/LH_2 as propellants.[6] The TRW ULCE test project consisted of a variety of tests from cold-flow activation tests (see Fig. 4a) to full-thrust ($650 \cdot 10^3$ lb_f) hot-fire tests this past year (see Fig. 4b). The culmination of the testing was a duration steady-state test at full thrust in late September 2000.

Future plans for E1 Cell 1 includes potential further testing of the TRW ULCE and an additional test of the $250 \cdot 10^3$ lb_f-thrust hybrid engine of the Hybrid Consortium that was previously hot-fired at E1 in 1999.

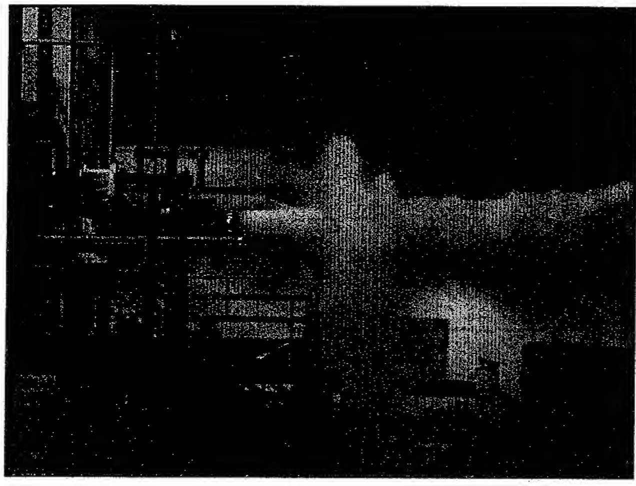

Fig. 4a. Cold-flow LO_2 activation test during the Ultra Low Cost Engine (ULCE) program at test stand E1 Cell 1. Flow is from left to right.

Fig. 4b. Hot-fire test of the TRW ULCE at E1 Cell 1. Approximately 1950 lb/s of propellant is burned in this test.

Test stand E1 Cells 2 and 3 are currently being modified to enable testing of oxygen and hydrogen turbopumps (TP) and preburners (PB) associated with the Integrated Powerhead Demonstrator (IPD) program. IPD integrated system testing is projected to follow circa 2003.

Test stand E2 Cell 1 recently completed Phase 1 testing of an RS-76 LO_2-rich subscale preburner in early 2000. A unique facility accomplishment during this test program was the ability to operate both the LO_2 and RP1 run tanks at 7000 psia, while operating the respective pressurant nitrogen bottles for these propellants as high as 13,500 psia. This high pressure capability allowed subscale LOX and RP1 injector/chamber demonstration. Such subscale demonstrations are economical risk mitigation techniques in advance of full-scale testing at E1 test stand.

Activity at test stand E2 Cell 2 from mid-year 2000 to current has been confined to design, construction and activation tasks in preparation for programs including Fastrac (MC-1). While Cell 2 does not have high pressure blowdown capability, it is well suited for serving as an engine test stand for RP1-based engines up to $100 \cdot 10^3$ lb_f thrust.

Test stand E3 has been very active in conducting hybrid-based and H_2O_2-based test programs recently. Lockheed-Martin Michoud Space Systems has developed a $60 \cdot 10^3$ lb_f thrust Hybrid Sounding Rocket (HYSR) for use at Wallops Island.[7] An image of the HYSR installed at E3 Cell 1 is shown in Fig. 5. The HYSR thrust chamber was successfully demonstrated in multiple firings at E3 Cell 1 during the past year and will be tested as an integrated system in FY01.

Hydrogen peroxide-based test articles such as the Boeing AR2-3, the Orbital Sciences Corporation Upper Stage Flight Engine (USFE) and Pratt and Whitney's Catalyst Bed have been recently tested at E3 Cell 2. SSC has gained significant experience in handling H_2O_2 propellant through conducting these test projects, including hydrogen peroxide concentrations up to 98%.

Coupled with continuous upgrades of the existing E complex test stands, a new facility, termed E4, is

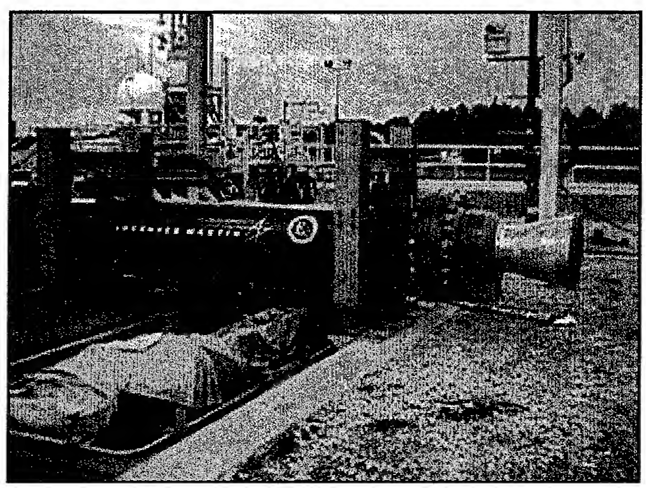

Fig. 5. Hybrid Sounding Rocket (HYSR) installed at the E3 Cell 1 test stand.[7]

being developed at SSC to accommodate large-scale Rocket Based Combined Cycle (RBCC) engine development. Sverdrup Technology, Inc. has developed an initial facility design, with details given by Smith and Wagner.[8]

Succinctly, the E4 facility is expected to be a single-cell test stand to be developed in two phases and to be dedicated to the testing of large-scale RBCC test articles at high turnaround rates. Completion of Phase 1 (circa 2003) will enable sea-level static testing capability of RBCC test articles up to $50{\cdot}10^3$ lb_f thrust, which is consistent with sub-orbital demonstrator vehicle thrust requirements. Propellant capabilities of E4 will include hydrocarbon, LO_2 and H_2O_2 initially, with LH_2 capability added at a later date when needed. Assuming successful test results and continued engine endorsement, the E4 test stand will be upgraded during Phase 2 to allow for static sea-level RBCC engine testing up to $500{\cdot}10^3$ lb_f thrust, consistent with payload-carrying orbital launchers. In addition, an air blowdown capability may be added to the test stand as to allow for the testing of the RBCC engine at low Mach numbers (M < 0.75) at reduced thrust levels ($20{\cdot}10^3$ - $50{\cdot}10^3$ lb_f).

ENGINEERING CAPABILITIES AND CHALLENGES

A number of unique capabilities and tools have been implemented in recent years at SSC towards the goal of more safe and cost-effective test services for the multitude of test projects mentioned in the previous section. This Center continues to make targeted investments each year in technologies with both near-term and far-term payoff in test preparation/execution, safety, process efficiencies, or better quality of product in terms of test data. A few noteworthy examples of such investments are presented here, but these are by no means a comprehensive list.

Computer-Aided Design of Facilities

Test projects require a substantial amount of preplanning that may begin as much as 12 to 24 months prior to first test, depending upon the scope and nature of the test requirements relative to the facility capability. Computer-aided design (CAD) is a tool for quickly determining how to accommodate the test article into the test cell. More often than not, the propulsion developer generates accurate solid models of the test articles (pumps, preburner, thrust chamber, or engine); and SSC now maintains an accurate representation of most of its facilities using the Pro/Engineer CAD package (a.k.a. Pro/E, widely used in the Aerospace industry). The facilities model and the test article can thus be coupled together to collaboratively design the major propellant supply systems to be utilized in conducting the testing. CAD is also a necessary tool for design of the test article support structure and the thrust takeout structure.

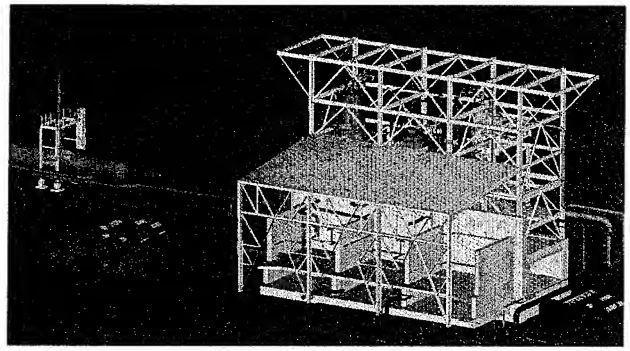

Fig. 6a. CAD model of test stand E1 consisting of major tankage and structure for 750Klbf thrust.

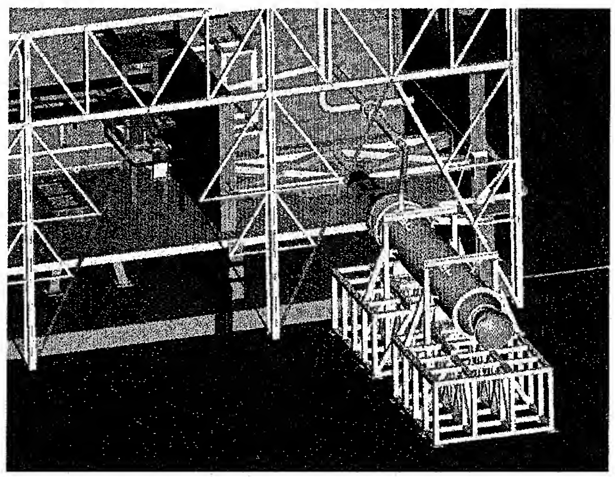

Fig. 6b. CAD model illustrating 250 Klbf hybrid motor installed in E1 Cell 1.

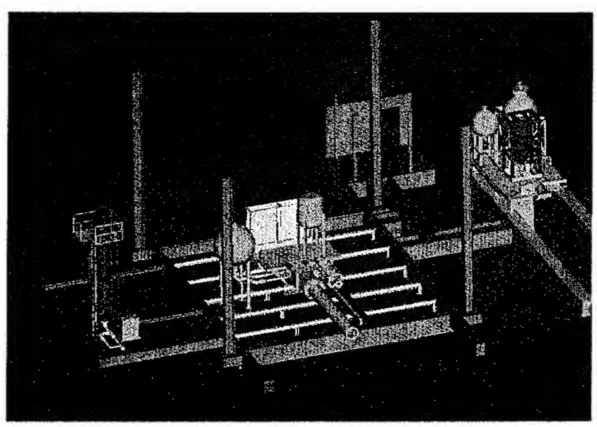

Fig. 6c. CAD model of test stand E3 consisting of major tankage and structure for up to 60Klbf thrust.

Representative Pro/E CAD models of the E1 and E3 test facilities are shown in Fig. 6a-c as examples of this capability. CAD models were extensively used to lay out the propellant supply pipe routing for several recent test projects such as the 250K hybrid motor (E1), 650K TRW thrust chamber (E1), the IPD LOX turbopump (E1), the X33 Aerospike engine (A1), and 60K HYSR (E3). Currently, programs such as the IPD LH turbopump (E1), and the X33 Aerospike dual-engine test (A1), are utilizing this capability.

Transient Fluid Dynamics of Propellant Runlines

The physical phenomena associated with cryogenic propellant supply systems, particularly at very high pressures, can pose many interesting and unique engineering problems that have to be addressed prior to conducting the first test. Not surprisingly, the flow and pressure drop characteristics of propellant flow at ultra-high pressure are a challenge by themselves, owing to the elevated pressures to 8500 psia, cryogenic temperatures to 40R, and large flow rates. However, a notable challenge is predicting and mitigating the specific problem of transient fluid hammer for liquid propellants. The issue was studied in-depth to prepare for the 250K hybrid motor testing, and subsequently for the IPD LOX pump and TRW 650K thrust chamber testing as well. The problem is presented below from a facility standpoint.

Severe liquid oxygen (LOX) runline vibration was observed during facility activation cold-flows at E1, but only during start and shutdown of the flow. Clearly, this was a symptom of fluid-hammer forces overwhelming the existing pipe support system. The root cause was the fact that the main flow control valve was actuated closed or open in a fraction of a second, resulting in tremendous surge forces/pressures as the LOX flow was suddenly started and stopped. Since peak fluid-hammer surge pressures are primarily a function of propellant density, flow rate, speed of sound in the fluid (i.e. LOX), and valve closure time, steps were taken to characterize the system using engineering analysis methods. Flow rates as high as 1700 lb/s, and system pressures as high as 2500 psia were investigated to address the immediate needs at E1, and pressures as high as 7000 psia were addressed for test facility E2. The analysis consisted of time-domain simulation of the system pressure and flow response to control valve operation. Subsequently, the transient pressures predicted throughout the system indicated a dynamic force-time-history for each pipe segment. The analysis also comprised finite element structural models of the runlines and supports to calculate effective structural support stiffness of runline segments for use in structural dynamic response analyses (incorporating stiffness effects due to axial, shear, bending, torsion, and so forth). Based upon the results of the fluid analysis, improvements to the structural supports were implemented and verified by further cold flow tests of the propellant system at both the E1 and E2 test stands. Additionally, the control valve actuation rate was slowed down to reduce the transient forces.

At test stand E1, both LOX and LH_2 propellant systems were characterized in work performed by InDyne analysts.[9] The majority of the work done correlating the fluid system models with test stand data was focused on the LOX system, since the LOX fluid-hammer forces are much larger than those for LH_2 due to fluid properties. Model correlation was performed for both the cold-flow and hot-fire data. Fig. 7a presents test data, while Fig. 7b illustrates the analysis results for the same case, where runline

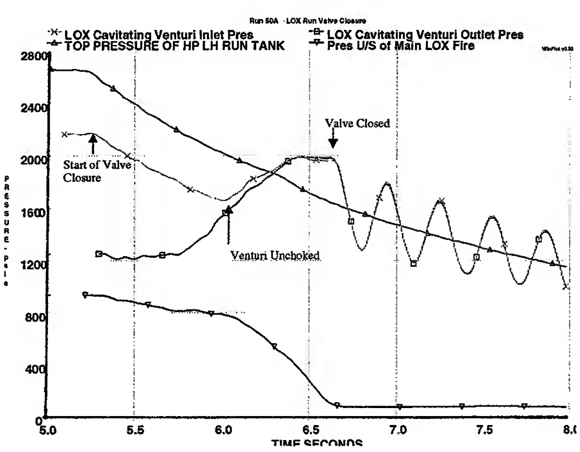

Fig. 7a. LOX system test data at E1.

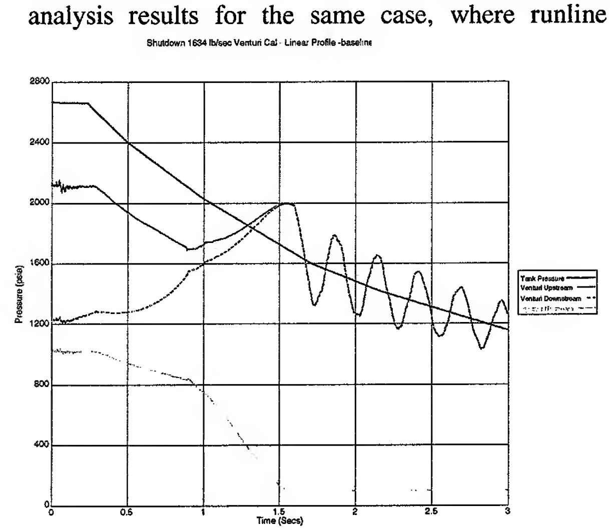

Fig. 7b. LOX flow simulation results at E1.[9]

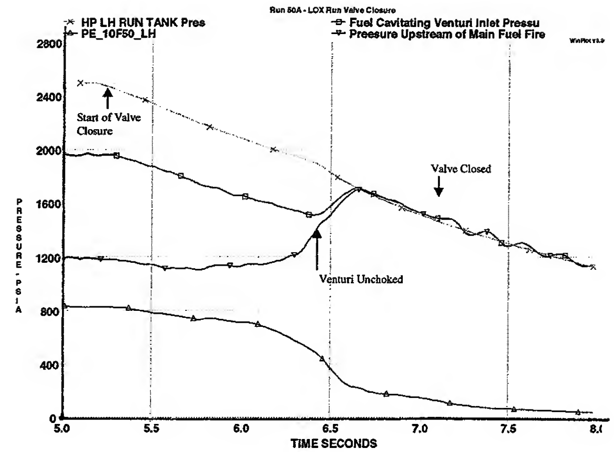

Fig. 7c. LH_2 system shutdown transient data.

pressure response at valve closure is of interest. Here the cavitating Venturi is the flow metering device and the shutdown fluid dynamics is influenced by the slew rate of the closing valve just upstream of the test article. The simulation (Fig. 7b) is successful in modeling the relatively large LOX shutdown pressure transients. In contract, the pressure transients resulting from LH_2 system operation proved to be very minimal for the flow rate of interest (cf. Fig. 8), and hence caused low dynamic loading on the LH_2 runline. The propellant system configuration was analogous to the LOX system. A slight fluid-hammer pressure oscillation is detectable once the valve is fully closed.

Further details of the above simulations are documented in by Arndt et al.[9] The tools developed in this effort are applicable to other propellants systems at these stands and other facilities as needed.

Test Stand Data Acquisition and Controls Systems

In addition to the many issues associated with mechanical and fluid systems, there are unique challenges with respect to data systems and control systems, often referred to simply as test stand "electrical systems." The design of the electrical systems in support of test projects, both hardware and software, is an essential element of the test preparation effort. In recognition of this, SSC has made substantial investments not only in modernizing the facility electrical hardware/software, but also in an "off-test-stand" simulation laboratory known as the Data Acquisition and Control Systems (DACS) Development Laboratory.

The DACS development laboratory provides an "off-line" Data Acquisition and Control Systems development, verification, troubleshooting, training, and new product & process evaluation capability. This minimizes the reconfiguration and preparation time between test projects since test facilities electronic/electrical systems are not encumbered by both test operations work and development work at the same time. Shown in Fig. 8 is part of the controls and data acquisition development and verification stations in the DACS lab. Fig. 9 is a view of a typical test stand control room.

The DACS Laboratory also provides a controlled laboratory condition for troubleshooting operational problems without having to change the test facility configuration. It may be used to verify equipment spares, and train operational personnel, where the training aspect is particularly useful since the DACS laboratory allows the operator to become familiar with the test stand electrical systems without impacting on-going test operations. Further, the laboratory is useful for evaluation of new DACS technologies for application to propulsion testing. Since the equipment and software is largely the same as that on the test facilities, the integration of new DACS techniques or technologies can be assessed in a controlled environment.

While the DACS Laboratory is still in its build-up phase, it has supported some of the test projects mentioned in this paper. Recently, an evaluation of valve tuning software was completed there to support

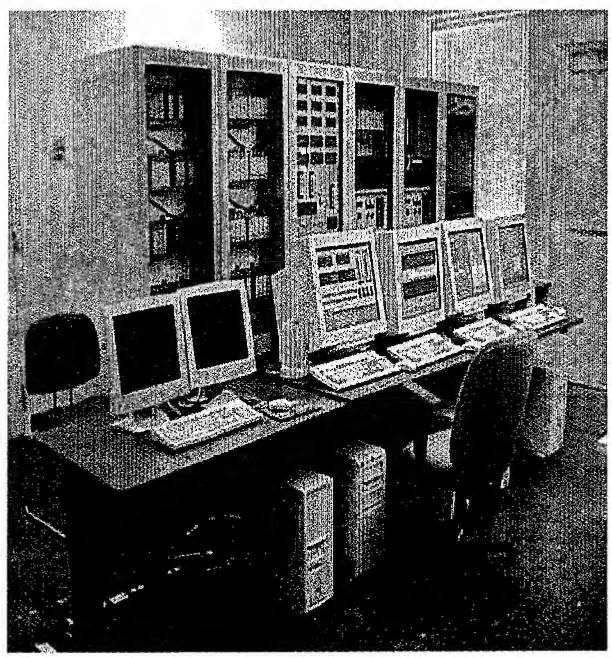

Fig. 8. Controls development and verification stations in the NASA Stennis Data Acquisition and Control Systems laboratory.

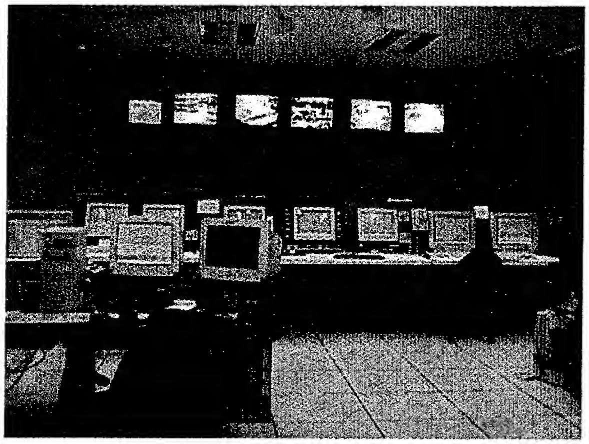

Fig. 9. A typical test stand control center at SSC.

test facility activation. The lab's data acquisition system supported checkout of the new E1 test facility automatic calibration system. Currently, the high speed digital data acquisition system is being configured to allow checkout of a new "direct-to-disk" data recording system. Future efforts include the development and verification capability for a multiprocessor control system environment, test facility flow simulation with the potential for hardware in the loop, and off-test-stand checkout of pneumatic & hydraulic control valves.

Test Technology Capabilities

Concurrent with the recent investments made by SSC in CAD systems, fluid modeling, DACS lab, and other test project oriented work, a number of mid-term and long-term targeted investments are being made under the purview of the Test Technology program. Some of these efforts directly impact test projects, whereas others are necessary or prudent in order to address future needs. [10]

Typically, the Test Technology group facilitates rocket engine testing by concentrating on specialized areas not traditionally supported core test project teams. Recent and past activities include engine exhaust plume spectroscopy, hydrogen fire detection, imaging and smoke/fog penetration, plume effects monitoring and prediction including acoustics monitoring and vibration assessments. In addition, Test Technology engineers, working together with in-house contractors and university faculty, engage in developmental efforts intended to address and resolve facility sensor, instrumentation, data acquisition and control challenges as they arise.

Examples of current developmental projects include investigations into non-intrusive flow measurement, automatic signal conditioning and data acquisition, intelligent health monitoring and diagnostics, advanced fiber optic sensor technologies, flow-induced vibration analysis techniques, next generation accelerometers and implementation of a sub-scale plume experimentation test-bed. A few representative technology projects are presented below in order to highlight this aspect of SSC engineering capabilities for propulsion testing.

Computing Cluster for Intensive Analytical Simulations

Lockheed Martin Space Operations - Stennis Programs (LMSO) at NASA/SSC designed and built a "Beowulf" Computing Cluster which is owned by NASA/SSC and operated by LMSO. A Beowulf Computing Cluster is relatively recent technology in which a collection of standard PC's operates as a single super-computer. This allows for super-computer performance to be achieved using off-the-shelf or commodity PC equipment and offers an excellent price to performance ratio. The design and construction of the NASA-SSC/LMSO cluster are described in detail by Woods and West.[11] The PC cluster is used primarily for Computational Fluid Dynamics (CFD) simulations, particularly in plume effects studies. The cluster has excellent further potential and plans are underway to add more capabilities, such as the addition of computationally intensive Finite Element Analysis software, as well as implementation of real-time data analysis/processing capability for high frequency measurements.[11]

Plume Effects Prediction and Monitoring

The prediction of full-field flow properties for a given plume is a critical capability with many immediate applications in propulsion testing. At NASA/SSC, the CFD predictions are often utilized to address convective and radiative heat impacts to facilities from rocket plumes as well as facility flarestacks. Safety concerns of overtemperature to facility systems are thus addressed in a quantitative manner, and appropriate mitigations are made based upon the assessments. The flowfield prediction capability is also used to guide or verify flame deflector design, a recent case being the E3 Cell 2 flame bucket. The flame bucket contour was selected after performing CFD simulations where the new design enabled much longer duration firings of test articles in the E3 Cell 2 test position. The simulations examined plume impingement forces and heating on an inclined deflector surface such that an optimum angle and coutour could be recommended. Fig. 10 presents an example of a CFD simulation of plume impingement performed on the SSC PC cluster, in this case onto a horizontal surface. At

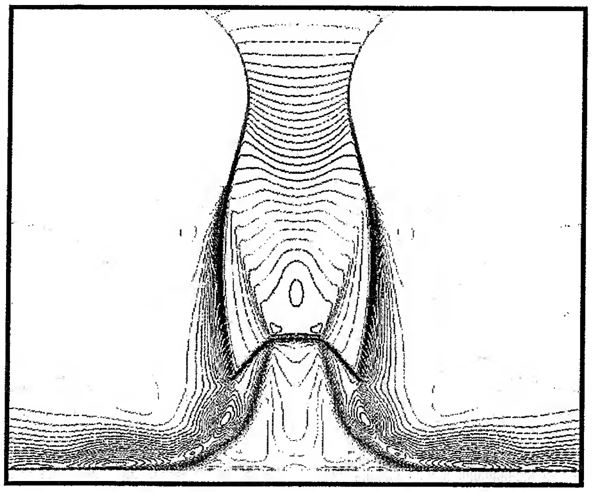

Fig. 10. A CFD simulation of a De Laval nozzle flow impinging upon a horizontal flat plate is performed on a PC cluster built by the Stennis Space Center test technology personnel.

SSC's request, the methods have been verified against laboratory test data by a more comprehensive series of solutions performed by Soni et al.[12] for inclined plates, and a variety of plume exhaust conditions.

The effects of rocket engine plume generated noise is also currently of interest, both from the standpoint of predicting the acoustic field for personnel safety, and also from the standpoint of recording the near-field sound levels for use by the engine and vehicle developers. The Test Technology program is accumulating a database of acoustic information by using microphone arrays to record sound levels on multiple test projects. Analogously, a significant amount of work is also being done to measure plume radiation levels near the engine exhaust. In fact, such data has already proved to be useful for vehicle heat shield designers.[13]

Advanced Data Acquisition Systems and Intelligent Health Monitoring

The rapid pace of advancements in computers, electronics, and instrumentation, along with miniaturization is enabling new approaches to data acquisition systems and utilization of data streams for health monitoring. The technology program at NASA/SSC is keeping cognizant of such advancements and working to adapt the applicable technologies to the test stand environment. The future of data and control systems, requires working outside of today's accepted paradigms. Examples include wireless, "intelligent" sensors with built-in signal conditioners, and advanced software to perform continuous qualitative and quantitative trending of test facility data streams from a network of such sensors (system by system). This particular activity was initiated by NASA SSC summer faculty work and is discussed in more detail by Figueroa et al.[14] Collaboration with investigators at other NASA centers (Marshall, Glenn, Kennedy Space Centers) is in process in order to facilitate SSC's advancement in this area. This is a new area of focus in Test Technology where the vision for the test stand is still being defined, but strong synergy is expected with Integrated Vehicle Health Monitoring (IVHM) activities of advanced launch vehicle developers.

In summary, the Test Technology program involves a variety of disciplines and cónducts test project oriented activities collaboratively with the help of civil servants, on-site contractors, off-site contractors, and a number of university partners and other academic affiliations.

CONCLUSION

The test facilities and test support capabilities at NASA SSC are being utilized more frequently and for more varied purposes that ever before. In addition to the heritage A and B Complex test stands, the newer E Complex test stands have added considerable additional test capability for full-scale rocket engine component or rocket engine system demonstrations. Test stand occupancy is near 100% with a variety of liquid fueled and hybrid fueled propulsive devices that are either being tested or in pretest planning stages. Test facility upgrades are in progress to enhance capabilities as required by near-term program needs as well as to posture the center to accommodate the testing needs of the next generation of propulsion devices. The NASA Space Launch Initiative, and the 2nd Generation and 3rd Generation propulsion developments in particular, are likely to sustain a high level of rocket testing activity.

The nature of recent and future propulsion test requirements are pushing the envelopes of facility capability in terms of flowrates, pressures, scale, and controls and data acquisition. Thus, engineering capabilities are being enhanced at SSC to address the particular needs as they arise. As the NASA Lead Center for Rocket Propulsion Testing, SSC continues to maintain and apply modernized CAD and analysis tools and capabilities to all test projects. Continuous improvement and modernization is also an important element of SSC's work where a number of test oriented technology projects strive to identify and address both current and future engineering challenges.

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